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An Improved Method for Phase Extraction Based on Gray Extremum

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Abstract

Surface deformation of an object can be measured by digital shearography through non-contact measurement with a simple device. It is always difficult to remove the noise of the speckle interference. Consequently extracting phase from a single fringe pattern without carrier-frequency is complex. Based on gray extremum, an improved method for phase extraction is proposed by using the improved image binarization algorithm in this paper. Through comparing the average value of eight neighbourhood points around each pixel with threshold value, the quality of binary image can be improved, and then the skeleton line can be extracted. Finally a smooth extremum image can be obtained. Experimental results show that the proposed method is simple, convenient and reliable.

Key words: *shearography; phase extraction; gray extremum method; binarization; skeleton*

1. Introduction

The result of optical interference method is always interference fringe with the phase information concerning measuring parameter. Through digital image processing, the information such as 3D topography, displacement, strain, vibration and temperature gradient, etc. can be obtained. Shearography is a modern optical measurement method on the basis of laser technology, image processing technology, computer technology, holographic interference and speckle pattern interferometry, precision instrument and automatic control technology. With the advantages of full measurement, non-contact, high precision

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and high sensitivity, independence of avoiding light and special shock protect, fast real-time and online, etc., it has already been an important measuring and detecting means.

The shearogram contains phase information about the object deformation with noises. Hence, the process from shearogram to 3-D topography refers to removing noises, extracting phase and calculating out-of-plane displacement. The traditional filtering method includes the mean filtering, the median filtering, frequency-domain filtering, the partial differential filtering and convolution filtering for shearogram [2]. Now space phase-shift method[3], time phase-shift method [4]and discrete-cosine-transform method can be used to extract phase information from more than two shearograms. Fourier-transform technique[5], spatial phase-shifting technique and phase-locked loop technique[6] can be used to extract phase information from single carrier-frequency shearogram. Skeleton interpolation method, regularized phase technique tracker and gray extremum technique[7] can be used to extract phase information from single shearogram without carrier-frequency. Phase extraction based on gray extremum method can be implemented in three steps: (1) Get the extremum map; (2) Normalize the map; (3) Calculate anti-trigonometric function and adjust symbols to get the wrapped phase map. The accuracy of the phase can be influenced directly by the continuousness and smoothness of the extreme map. An improved process of getting the extreme map will be introduced in this paper.

2. Principle

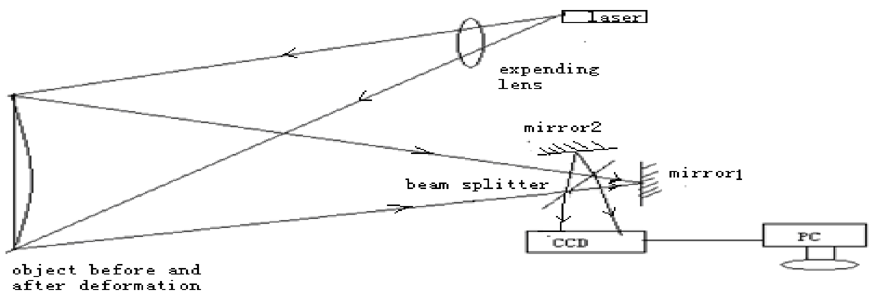

Fig.1. The experimental principle of electronic shearography

The experimental principle of a simple shearography is shown in Fig.1. A laser beam is projected by beam-splitter onto the object and is reflected by the style of speckle. It is divided into two beams. One is injected to mirror1, the other to mirror2. Then the two segments recombine after they emerge from the beam splitter. Mirror2 is titled a small angel about x-axis. Mirrror1, mirror2 and the beam splitter constitute the Michelson interferometer shear set. Two different adjacent points of the object become one point through the Michelson interferometer shear set to form interference. Two same images shearing with each other will be observed. Two interferograms can be obtained before and after the object deform. The shearogram can be obtained through image subtraction [8].

The intensity I of the interferogram before object deformation can be expressed by:

$$I = 2I_0(1+\gamma\cos\varphi) \qquad (1)$$

where, I_0 is the intensity of background, γ is the modulation of the interference term, and φ is the random phase difference.

After the object deforms, the intensity of the interferogram can be expressed by:

$$I' = 2I_0(1+\gamma\cos(\phi+\Delta)) \qquad (2)$$

Both of the Eq. (1) and (2) contain the random phase, and the Eq. (2) also contains the phase difference Δ corresponding to the deformation information of the object. Hence an interference map [9] can be obtained through the subtraction of the Eq. (1) and (2). It can be described by:

$$\left|I_s\right| = \left|4I_0\gamma\left[\sin(\varphi+\frac{\Delta}{2})\sin(\frac{\Delta}{2})\right]\right| \tag{3}$$

where, is the relative phase difference. Obviously, if Δ=2nπ, n=1,1,2,3…,sin(Δ/2)=0, the fringes are dark, while Δ=(2n+1)π, n=1,2,3…, the fringes are bright.

From the relationship between the relative phase difference and the gray value, it can be known that there are several steps to get the phase map. (1) Remove the low-frequency components; (2) Make linear transformation of the gray of each fringe; (3) Calculate the anti-trigonometric function. The traditional method for the linear transformation is to use a 3*3 window to search the maximum and the minimum of the whole map, and add 1 to the maximum, and then make the minimum minus 1. In the midst of them is 0. The result is always discontinuous and split, which need much more additional processing. In this paper, the extremum map can be calculated by using the method of the image binarization and then the skeleton line can be extracted.

3. Calculation of Extremum

3.1 Image Binarization

The main idea of the binarization is the original binary method, which sets a suitable threshold *T* for the whole map and converts the continuous variation of the gray stripes into binary stripes. Namely,

$$I_s'(i,j)=\begin{cases}255 & I'(i,j)\geq T\\ 0 & I'(i,j)<T\end{cases} \tag{4}$$

The result is always rough if using the above-mentioned algorithm. This paper uses the algorithm of Merriman-Bence-Osher (MBO) [10] to improve the edge of the image to make the shape regular. The algorithm of MBO is a process of iterations for many times. One of them can be described by:

$$S_X = \begin{cases}1, & x\in X\\ 0, & x\notin X\end{cases} \tag{5}$$

$$\begin{cases}\partial u = \nabla^2 u\\ u(x,y,0)=I(x,y)\end{cases} \tag{6}$$

where, S_X is the characteristic function of the binary area.

(1). Set S_X is the starting value and then the solution $S_{X,t}$ can be gotten with the equation of heat conduction.

(2). Define

$$X_1 = \{x \mid S_{X,t} \geq T\} \tag{7}$$

Get the new binarization map S_{X_1}, where, *T* is the threshold.

(3). If $X = X_1$, go back to (1).

Actually, the algorithm of the MBO is the binarization of the iteration result after implementing the equation of heat conduction. Obviously, comparing the gray value of the image with the threshold is important to obtain a better binarization map. Hence the eight coherent average value of one point instead of one point is compared with the threshold in this paper. If the eight coherent average value is greater than the threshold, set the point 1, or else set it 0. Replace the equation *(7)* with *(8)*, the skeleton accuracy can be improved.

$$X_1 = \{\overline{x} \mid S_{X,t} \geq T\} \tag{8}$$

3.2 Extraction of skeleton line

Extraction of the skeleton line is to thin the edge of the binarization map to the width of a single pixel. Here is the most popular method of Hilditch thinning [11]. The Hilditch thinning algorithm can be expressed with Table1:

Table 1.one point with eight adjacent points

A	B	C
H	O	D
G	F	E

Definition 1: For any point O of binary image, set it's eight adjacent point for A, B, C, D, E, F, G, H.

Definition 2: M (O) is the number about the adjacent area value of nonzero.

Definition 3: N (O) is the number of the points A, B, C, D, E, F, G, H, A jumps one after another from 0 to 1.

If all of the 4 conditions below are true, set the point zero until the width become single pixel.

(1) $2 \leq M(O) \leq 6$

(2) N (O) =1

(3) A、C、G=0 or N(A) $\neq 1$

(4) A、C、E=0 or N(C) $\neq 1$

The result of the extremum map is smooth and continuous and it is the benefit of the next calculation of the wrapped phase.

4. Experiments and results

The subtraction of the shearogram fringe maps before and after the deformation of a circular aluminum with a thickness of 2 mm is shown in Fig. 2(a). Fig 2(b) is the shearogram after flitting.

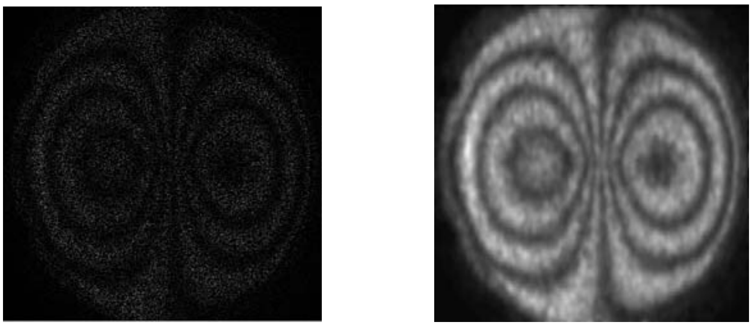

Fig. 2. (a) shearogram fringe map after subtracttion; (b) shearogram after flitting

The extremum map can be obtained just as this paper introduced and is shown in Fig. 3(a) and Fig. 3(b) is the extremum map processed by traditional method.

5. Conclusions

It is difficult to extract phase from a single fringe pattern because the shearogram is high-noisy and the extremum map is not accurate enough. This paper proposes a method to get a smooth extremum map through image binarization and thinning algorithm. The experimental results show that the method is easier and more accurate.

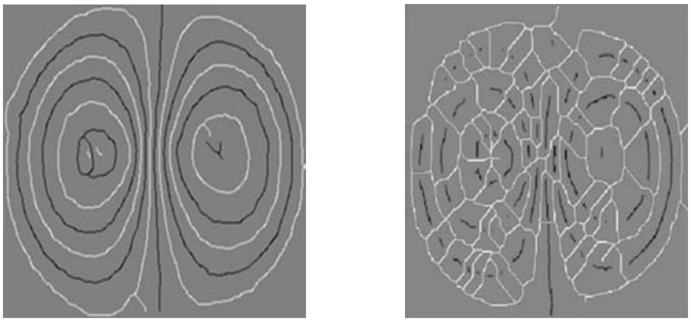

Fig. 3. (a) extremum map in this paper; (b) extremum map of traditional method

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